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(54) Antenna Arrangement for Emitting Extremely Low Frequency Waves

In order to prevent high voltage build-up on the antenna conductor with respect to the earth in antenna arrangements for emitting extremely low frequency waves, a plurality of partial capacitance elements are inserted distributed across the length of the conductor for the sectional compensation of the inductive reactance of the antenna arrangement. For mobile systems the partial capacitance elements are connected detachably to the individual sections of the antenna conductor, preferably by means of connecting devices with strain relief.

## Description

The invention relates to an antenna arrangement for emitting extremely low frequency waves (ELF) pursuant to the preamble of patent claim 1. Such an antenna arrangement is already known from M.L. Burrows: "ELF Communications Antennas" (Peter Peregrinus Ltd., 1978), Chapter 3, pages 74-90.

As described there in closer detail, antennas for emitting extremely low frequency wave signals usually consist of one or more insulated conductors, which are laid on the earth's surface or are suspended above ground on suitable supports. At sea cables floating on the water surface are used. One end of the conductor or conductors is connected directly to the potential of the ground (or the seawater) by suitable ground electrodes. The transmission energy is fed between the other end and a second ground electrode. In particular with land systems feeding can also occur in any random other location of the antenna conductor, preferably in the center between the ground electrodes.

The antenna current flows from the supply point via the antenna conductor to the ground electrode, from there through the ground or the seawater to the second ground electrode and from there if applicable via the appropriate antenna section back to the supply point. Since even antennas of 10 to 20 km length are short compared to the free space wavelength, the same current intensity exists everywhere on the antenna. The arrangement represents a large conductor loop. The input resistance measured at the supply point consists of an inductive reactive component  $j\omega L$  and an active component  $R$ , which is provided by the conductor resistance, the transition resistance of the ground electrodes and the eddy current losses in the ground or seawater.

As both theory and measurements in practice show the reactive component in the frequency range of interest, e.g. carrier frequencies between 300 and 1200 Hz, is always significantly greater than the active component. To ensure that the transmitter is not loaded with high reactive power, the reactive component is compensated at the supply point by a series capacitance so that the transmitter output is loaded with pure effective resistance. Together with said series capacitance the antenna represents a series resonant circuit of  $> 1$  that is adjusted to the carrier frequency. Accordingly voltage build-up develops. With transmission power levels of about 10 to 100 kW very high voltage with respect to the earth can occur on the interface of the series capacitance with the antenna and the following antenna section. In order to avoid breakdowns and flashovers and protect the operators, comprehensive and costly measures are then required. They relate to the design and the insulation of the antenna, the series capacitance, the corresponding connecting elements and, to the extent that several operating frequencies were used, the switchgears for changing the series capacitance. Especially critical are the conditions with mobile systems with cables laid on the ground or floating on the water as antennas because here also the protection of personnel that is not involved, but accidentally approaches the antenna must be guaranteed.

It is therefore the object of the present invention to eliminate or at least significantly reduce the risks arising from high voltage in an antenna arrangement of the kind provided in the preamble of patent claim 1.

The invention is described in patent claim 1. The dependent claims contain beneficial embodiments and further developments of the invention.

The antenna arrangement pursuant to the invention is characterized above all by the moderate voltage levels with respect to the earth on the transmitter output and on the antenna conductor, even with large transmission power levels, so that hardly any risks exist for persons or even the system itself. Beyond that, however, additional significant advantages result in terms of material requirements for a possibly required mobility of the transmission system:

Instead of lines, capacitance elements, switches and connecting elements in the medium voltage field, components from the low voltage field can be employed. Since the latter are significantly smaller and lighter and in part have a simpler inner design, volume and weight are saved. This is very essential especially for mobile systems.

The low voltage antenna cables, which compared to medium voltage cables are comparatively thin and flexible, can be laid more quickly and require less effort for transport and storage. The same applies for resuming an antenna. This minimum effort is likewise a benefit for the mobility aspect.

The invention will be explained in the following based on exemplary embodiments while referencing the illustrations. Shown are:

Fig. 1 the basic design of an antenna arrangement pursuant to the invention

Fig. 2 the arrangement pursuant to Fig. 1 with equivalent circuit diagrams for the individual sections

Fig. 3 another arrangement with equivalent circuit diagrams.

Fig. 1 represents the transmitter 1, the outputs 2 and 3 of which are connected to the antenna input and the ground electrode 4. The other end of the antenna conductor 12 is grounded via the ground electrode 6. Directly after 6 the capacitance element 8 is arranged, which is selected such that it compensates the inductive reactance of the antenna section between 8 and the subsequent capacitance element 11. Accordingly 11 compensates the reactance of the antenna section 11-14 etc. Finally the capacitance element 15 compensates the reactance of the antenna section 15-2, i.e. the section closest to the transmitter.

Fig. 2 shows the equivalent circuit diagram of the arrangement. 5 and 7 are the transition resistances of the ground electrodes 4 and 6. 9, 12 and 16 represent the effective resistances (actual resistances, resistances corresponding to eddy current losses in the ground, etc.), 10, 13 and 17 represent the reactances of the antenna sections 8-11, 11-14 and 15-2. When the transmitter current flows through the conductor circuit, on the transmitter-side connection of 8 the vector sum from the voltage drops on 7 and 8 is present with respect to the earth, on the ground electrode-side connection of 11 on the other hand the sum of the voltage drops on 7 and 9 is present because the reactive voltage on 10 is compensated by the opposite one on 8. The same applies accordingly for the subsequent

section, where the reactive voltage on 11 compensates that on 13 etc. Finally, the reactive voltage on 15 compensates that on 17 in the section closest to the transmitter. The voltage on the transmitter output 2 with respect to the earth corresponds to the sum of voltages on the ground resistances 5 and 7 and on the effective resistances of all antenna sections. The greatest voltage with respect to the earth in the entire system occurs on the transmitter-side connection of 15. It corresponds to the vector sum from the sum of the voltage drops on all effective resistances with the exception of 16, but including the ground resistances and the voltage drop on the reactance 17. Quantitatively the relation is described by the following equations (1) and (2). For clarity reasons it is assumed that  $n$  antenna sections are all identical and that their equivalent circuits consist of the effective resistance  $R$  and the reactance  $j\omega L$ . Also the ground resistances should be equal and each amount to  $R_E$ . When the antenna is supplied with the current  $I_S$ , the greatest voltage with respect to the earth when applying the invention is

$$U_{\max 1} = I_S \cdot \sqrt{(\omega L)^2 + ((n-1) \cdot R + 2 \cdot R_E)^2} \quad (1)$$

when applying the familiar compensation through a series capacitance on the input, however,

$$U_{\max 2} = I_S \cdot \sqrt{(n \cdot \omega L)^2 + (n \cdot R + 2 \cdot R_E)^2} \quad (2).$$

Since  $\omega L$  in the common frequency range is 5 to 8 times greater than  $R$ ,  $U_{\max 1}$  is significantly smaller than  $U_{\max 2}$ . Hereby it must be taken into consideration that  $U_{\max 2}$  exists not only on the interface of the capacitance element to the antenna cable, but also on the subsequent antenna section. The voltage with respect to the earth then decreases roughly equally with increasing distance.

The voltage with respect to the earth can be further reduced in the familiar fashion when the supply of the transmitter current occurs not on an antenna end, but in the path of the antenna, preferably its center. Fig. 3 shows the equivalent circuit. The greatest voltage occurs for the above-described reasons on the capacitance elements closest to the transmitter on the transmitter side. When the antenna against consists of  $n$  identical sections with capacitance elements, then the greatest voltage with respect to the earth (3) results from

$$U_{\max 3} = I_S \cdot \sqrt{(\omega L)^2 + ((n/2 - 1) \cdot R + R_E)^2} \quad (3).$$

Since  $\omega L$  as mentioned before is generally greater than  $R$ ,  $U_{\max 3}$  is greater than  $U_{\max 1}/2$ .

Pursuant to a preferred embodiment, the partial capacitance elements are dimensioned such that the voltage amounts on the antenna input and on the input-side connection of the capacitor closest to the input are identical. With  $n$  identical partial sections, which each have an effective resistance  $R$  and a reactance  $\omega L$ , the most favorable value for the partial capacitance elements results from

$$C = \frac{2L}{n \cdot (2n - 1) \cdot R^2 + 2n \cdot R \cdot R_E + n \cdot (2n - 1) \cdot \omega^2 \cdot L^2} \quad (4).$$

For this embodiment the lowest voltage with respect to the earth is present on the individual antenna sections.

In the practical implementation of the invention the operating mode of the extremely low frequency antenna must be taken into consideration. If it is used within a limited frequency band under defined ambient conditions, then the capacitance elements can be firmly installed in its path. It is useful if stretched flexible sheaths are used, which contain several capacitor windings one after the other. The capacitance elements can then be stored jointly with the antenna cable on a cable drum and be applied from there. Since compensation is optimal only at one frequency, here and also in the following arrangements an additional, variably adjustable network is arranged between the transmitter output and the antenna input, thus allowing the remaining reactance to be compensated.

If the antenna is supposed to operate in a broader frequency band, then the capacitance elements have to be adjusted to the respective operating frequency. In the case of a length of several kilometers the antenna cable cannot be accommodated on a drum anyhow. Therefore pieces with the selected section length are wound on a drum. The capacitance elements are accommodated in water-proof housings, or in floating housings in the case of ocean applications. The ends of the cable sections and the housings are equipped with plug-type devices so that they can be inserted into the antenna path without requiring significant time when laying them. The plug-type devices or an additional device also serve the strain relief. Each housing can contain one or more capacitance elements. In the first case, the operating frequency must be known when laying the antenna so that the corresponding capacitance values can be set. In the second case the capacitance elements can be brought to the necessary value for the respective operating

frequency by manually switching them or by remote control. As mentioned in the above paragraph, no exact compensation of the reactance of each antenna section is required. The capacitance in the housings can also be composed of normal values, e.g. of the IEC series. Compensation of the remaining reactance is assumed by the additional compensating network.

#### Patent Claims

1. Antenna arrangement for emitting extremely low frequency waves, comprising a stretched antenna conductor that is connected on its ends to earth potential and is insulated with respect to the earth in its remaining path, with a transmitter for exciting an antenna current in the conductor and with a series capacitance element in the antenna circuit for compensation of the inductive reactance of the antenna arrangement, **characterized in that** several partial capacitance elements are arranged as series capacitance elements across the length of the conductor.
2. Antenna arrangement pursuant to claim 1, characterized in that the partial capacitance elements are dimensioned such that they sectionally compensate the inductive reactance of the conductor sections, which are separated by the partial capacitance elements.
3. Antenna arrangement pursuant to claim 1 or claim 2, characterized in that the partial capacitance elements are arranged in an approximately equidistant manner across the length of the conductor and are evenly dimensioned.
4. Antenna arrangement pursuant to one of the claims 1 to 3, characterized in that a variably adjustable compensating network is additionally installed between the transmitter output and the antenna connection.
5. Antenna arrangement pursuant to one of the claims 1 to 4, characterized in that the partial capacitance elements can be switched to several discrete values by means of switchgears.
6. Antenna arrangement pursuant to claim 5, characterized in that the switchgears can be actuated by remote control.
7. Antenna arrangement pursuant to claim 6, characterized in that remote control of the switchgears occurs electrically via the antenna conductor.
8. Antenna arrangement pursuant to one of the claims 1 to 7, characterized in that the partial capacitance elements can be connected on at least one side to the conductor sections via easily detachable connecting devices.
9. Antenna arrangement pursuant to claim 8, characterized in that the connecting devices comprise plug-type devices.
10. Antenna arrangement pursuant to claim 8 or 9, characterized in that the connecting devices comprise strain-relieving devices.
11. Antenna arrangement pursuant to one of the claims 1 to 10, characterized in that the partial capacitance elements are accommodated in water-proof housings.
12. Antenna arrangement pursuant to one of the claims 1 to 11, characterized in that low voltage technology components are used.
13. Antenna arrangement pursuant to one of the claims 1 to 12, characterized in that supply of the transmitting energy occurs in any random location, preferably in the center of the antenna conductor.

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1 page drawings

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